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Emissions of Naturally Occurring Radioactivity: Underground Zinc Mine and Mill

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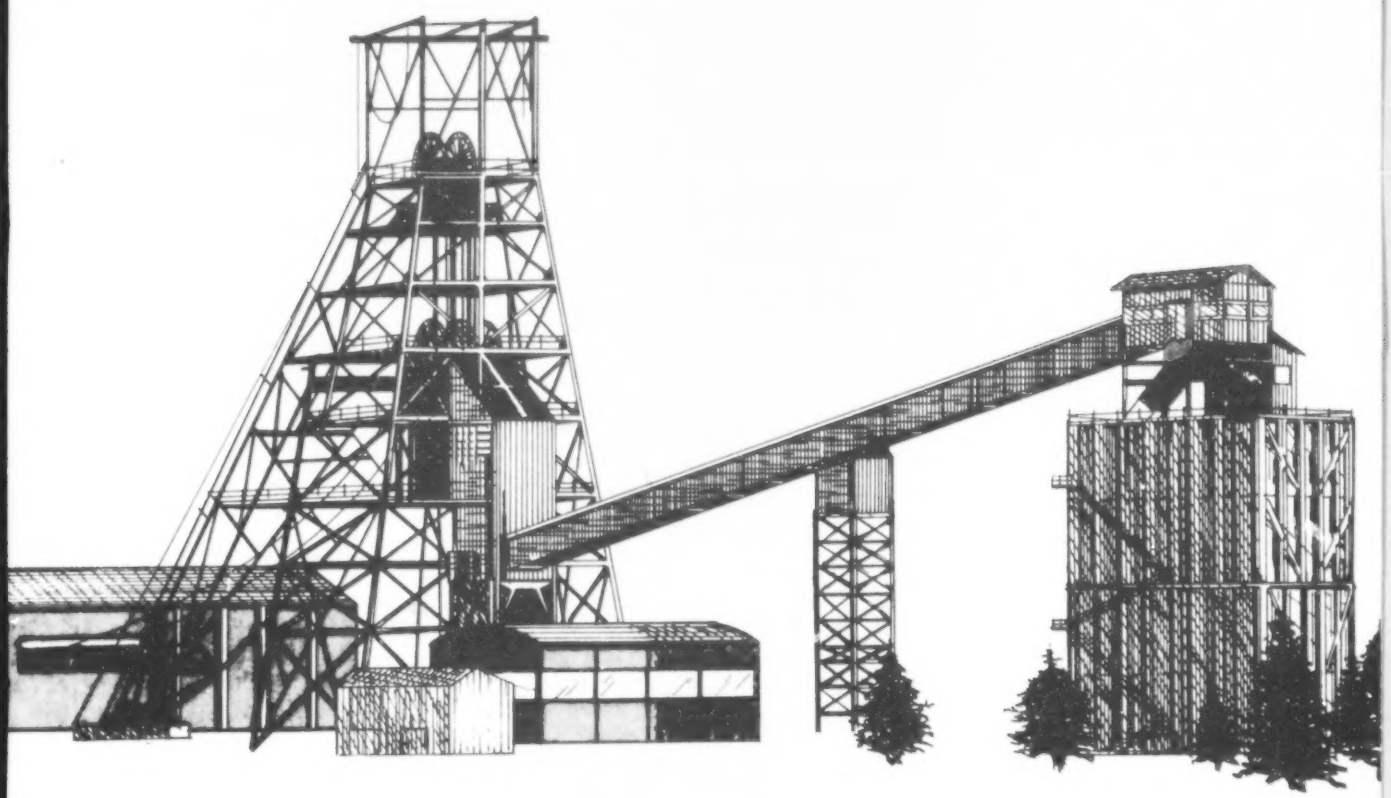

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16. ABSTRACT

Atmospheric emissions of naturally occurring radioactivity were measured from an underground zinc mine and mill. The only significant radioactive emission from the mine or mill was radon-222. An estimated 230 curies of radon-222 is released annually from the mine. The primary source of radon is believed to be the high influx of water which is pumped from the mine at the rate of 110 cubic meters per minute.

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EMISSIONS OF NATURALLY OCCURRING RADIOACTIVITY UNDERGROUND ZINC MINE AND MILL

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PREFACE

The Office of Radiation Programs (ORP) of the U.S. Environmental Protection Agency (EPA) conducts a national program for evaluating exposure of humans to ionizing and nonionizing radiation. The goal of this program is to develop and promote protective controls necessary to ensure the public health and safety.

In response to the 1977 amendments to the Clean Air Act, the Las Vegas Facility was given the responsibility to collect field data on emissions to the atmosphere of natural radioactivity from mining, milling, and smelting of minerals other than uranium and coal. This report is one of a series which describes an individual facility and its associated radioactivity emissions.

ORP encourages readers of the report to inform the Director, ORP-Las Vegas Facility, of any omissions or errors. Comments or requests for further information are also invited.

Wayne A. Bliss
Acting Director, Office of
Radiation Programs
Las Vegas Facility

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I BACKGROUND

The Clean Air Act as amended in August 1977, required the Administrator of the Environmental Protection Agency (EPA) to determine whether emissions of radionuclides into ambient air should be regulated under the Act. In December, 1979, the Administrator listed radionuclides as a hazardous pollutant under Section 112 of the Clean Air Act.

The naturally occurring radionuclides most likely to be emitted in significant quantities are those in the uranium-238 and thorium-232 decay series. These radionuclides and their daughter products occur naturally in widely varying amounts in the soils and rocks that make up the earth's crust. Average values for uranium-238 and thorium-232 in soils are approximately 1.8 ppm (0.6 pCi/g) and 9 ppm (1 pCi/g) respectively (NCRP, 1975).

Almost all operations involving removal and processing of soils and rocks release some of these radionuclides into the air. These releases become potentially important when the materials being handled contain above-average radionuclide concentrations or when processing concentrates the radionuclides significantly above the average amounts in the soils and rocks.

Because mining and milling operations involve large quantities of ore, and because there was little information about how these activities release radioactive emissions, EPA, in 1978, began to measure airborne radioactive emissions from various mining, milling, and smelting operations.

Operations were selected for study on the basis of their potential to emit significant quantities of naturally occurring radionuclides to the atmosphere. Some of the factors in the selection included typical mine size, annual U.S. production, measured working levels of radon daughters in underground mines and associated ventilation rates, production rate and process of individual facilities, and previous association with naturally occurring radionuclides. Usually, we chose to look at large facilities in order to get statistically significant results.

These surveys were screening studies designed to identify potentially important sources of emissions of radionuclides into the air. Any such sources can then be studied in detail to determine whether or not a national emission standard for hazardous pollutants is needed under the Clean Air Act.

II INTRODUCTION

The Mine Safety and Health Administration (MSHA) makes periodic measurements of radon daughter working levels (WL)* in underground mines. Zinc mines are included among those having the highest measured WL (Goodwin, 1978). The Office of Radiation Programs (ORP) selected the zinc industry for inclusion in this study because of the potential for releases of radioactivity indicated by the radon daughter concentrations. Only 45 underground mines were found to have radon daughter concentrations in excess of 0.1 WL during 1976 and 1977. Seven of these were zinc or lead-zinc. The Friedensville mine, with an average reported radon daughter concentration of 0.58 WL near the portal, had the fourth highest concentrations during that period.

Engineering-Science (E-S) performed the sample collection and emission measurements under contract to EPA. E-S has reported their results separately (Engineering-Science, 1978). ORP, E-S, and MSHA representatives visited the Friedensville mine and mill for familiarization and to select appropriate sampling sites.

E-S conducted the sampling and measurement program during the week of September 25-29, 1978. The author accompanied E-S on the survey and performed the WL measurements in the mine. In addition to sample collection, E-S installed a temporary meteorology station on the tailings pile to measure wind speed and direction. Eberline Instrument Corporation (EIC) did the radiological analysis of the samples.

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*The WL is defined as any combination of shortlived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 meV of potential alpha energy (U.S. Public Health Service Publication No. 494, 1957)

E-S described the sample collection and reported the parameters measured, including sample volumes and discharge point air flow rates. This report combines the data from radiological analyses with data reported by E-S to give the radionuclide concentrations and rates of discharge.

III SUMMARY

The zinc mine and mill at Friedensville, Pennsylvania was chosen because of its high production rate and the high WL measurements reported by MSHA. Particulate and gaseous emission samples were collected from all important emission points and radon flux measurements were made on the mill tailings. Radon-222 was the only radionuclide definitely measured above ambient levels from any emission point. It was determined that the mine exhausts approximately 230 Ci/y of radon while the radon from the mill totals less than 1 Ci/y. The radon flux from the tailings pile was found to be approximately one-third of that from the native soil. The reduction in radon flux from the soil surface as a result of being covered by the tailings piles about offsets the radon generated by the mill.

Natural radioactivity concentrations in the ore and process samples were below the average values normally observed in limestone, which makes up the bulk of the ore. The most likely explanation for the high radon concentrations observed in the mine exhaust is the large quantity (110 m^3/min) of water which flows into the mine. A water sample collected at the surface discharge from the mine had a radon-222 concentration of 50 pCi/l. This was probably a few percent, at most, of the original concentration in water entering the mine.

IV MINE OPERATIONS

The Friedensville mine ore is amorphous zinc sulfide (a form of sphalerite) in a limestone matrix. The ore runs approximately 6 percent zinc. Friedensville has a history of zinc mining; several small open pit zinc mines had been operated in the vicinity during the past century, and in 1958 New Jersey Zinc Company opened the underground Friedensville Mine.

The mine is a room and pillar operation with 10 levels in use at the time of the survey. A single vertical shaft provides for personnel access, ore removal via two skips, and inflow of ventilation air. An incline connecting all levels exits through one of the old open pit mines and provides a route for loaders and trucks to move ore. A series of dampers and air locks controls air flow through the mine. This system not only assures ventilation of all actively worked areas, but also prevents unnecessary air movement through unused mine areas. Ventilation air exhausts through the incline portal at the bottom of the open pit mine.

Ore mined on the various levels is hauled to ore passes where it falls to the primary crusher located 585 m (1920 feet) below the surface. The ore is crushed to a size of approximately 7.5 to 13 cm (3 to 5 inches) and is hauled to the surface in 6-1/2 ton capacity skips.

The Friedensville mine is reported to be the wettest mine in the western hemisphere; considerable infiltration of water occurs at all levels. Water is carried by open drains to sumps and is pumped through a series of water raises to the surface, receiving considerable aeration on the way. On the surface, water passes through two lagoons to permit settling of solids before being discharged to Saucon Creek. Water flow rates were 110 m^3/min (29,000 gpm) at the time of the survey.

Mining was conducted around the clock with the exception of the second and third shifts (3:00 p.m. to 7:00 a.m.) on Sundays and holidays. Three ore faces were worked simultaneously. Two or three faces were blasted each shift, generally during lunch or at the end of a shift.

V MILL OPERATIONS

Ore carried to the surface in the skips is dumped into a skip bin. Ore from the skip bin is screened at 2.2 cm (7/8 inch) with oversize going to a secondary crusher. Airborne particulates generated during ore transfer, screening, and secondary crushing, are drawn through a Rotoclone emission control and vented through a 35.6- by 45.7-cm (14- by 18-inch) duct above the roof of the secondary crusher. The exhaust is approximately 6 m (20 feet)

above ground level. Undersize from the 7/8-inch screen and crushed ore from the secondary crusher are conveyed to an ore bin. Ore from the bin is screened at 0.95 cm (3/8 inch) and oversize goes to a tertiary crusher. Crushed ore from the tertiary crusher and undersize (3/8 inch) are carried by bucket elevator to a surge bin which feeds two identical concentrating processes identifed as "East" and "West." Airborne particulates produced during screening, tertiary crushing, and ore transfer via the bucket elevator are controlled by a Rotoclone. The Rotoclone discharges through a 36.2- by 47.6-cm (14.25- by 18.75-inch) stack approximately 21 m (70 feet) above the ground.

The ore in each concentrating process passes through a rod mill then through a classifier. Sands from the classifier are further ground in a ball mill and returned to the classifier. Both processes are conducted wet and generate negligible airborne particulates. Conditioners are added to the aqueous slurry from the classifier overflow which is then processed by a series of flotation cells.

The final zinc sulfide concentrate resulting from the East and West concentrating processes is combined and concentrated on a seven-unit disk filter. From there it passes through a dryer to storage. Airborne particulates from the dryer are collected and passed through a Rotoclone which discharges through a 45.4-cm (17.9-inch) diameter stack approximately 17 m (55 feet) above ground.

The tailings produced are basically a clean, fine limestone sand. About 15 percent of the tailings are processed by hydroclones to produce "spigot", a damp sand product. Ten to 15 percent of the spigot product is dried, size classified, and stored in silos to be bagged or sold as bulk agricultural limestone. The rest of the spigot product is mixed with cement to be used for mine fill or is sold as damp bulk limestone. The tailings not used or sold are pumped as a slurry to tailings piles about one-half mile north. Some limestone is also removed from the tailings piles and sold as agricultural limestone. Airborne particulates generated during limestone drying are controlled by means of a packed scrubber discharging through a 50.8-cm (20-inch) diameter stack approximately 15 m (50 feet) above ground. The silo

loading system is also a generator of airborne particulates. These are controlled by a hydrofilter atop the silo. Discharges from the hydrofilter are through a 61-cm (24-inch) diameter stack about 18 m (60 feet) above ground. Figure 1 is a schematic of the Friedensville operation from primary crusher through shipment of the concentrate product.

Mill operation is continuous except for the first shift (7:00 a.m. to 3:00 p.m.) Mondays when it is shut down for maintenance. The secondary crusher operates during the second and third shift daily except Sunday. The limestone drying and silo loading systems operate only as needed, approximately 650 hours per year.

VI SAMPLING LOCATIONS AND PROCEDURES

A. Site Selection

E-S and EPA personnel determined sampling locations and types of samples to be collected during their pre-survey visit. Air sampling locations selected were:

1. Mine ventilation exhaust (mine portal)
2. Secondary crusher Rotoclone exhaust
3. Tertiary crusher Rotoclone exhaust
4. Mill building fugitive emissions (powered roof vent)
5. Concentrate dryer Rotoclone exhaust
6. Linestone dryer scrubber exhaust
7. Silo loading system hydrofilter exhaust
8. North side of old tailings pile, "A"
9. Radon flux from tailings piles and "undisturbed" soil
10. Background (ambient) air samples between mill and mine portal (pump house)
11. Background (ambient) air samples at north side of mill

B. Sampling Techniques

Most samples were collected using EPA reference methods (40 CFR 60). Stack sampling points were selected according to EPA Method 1. Stack gas

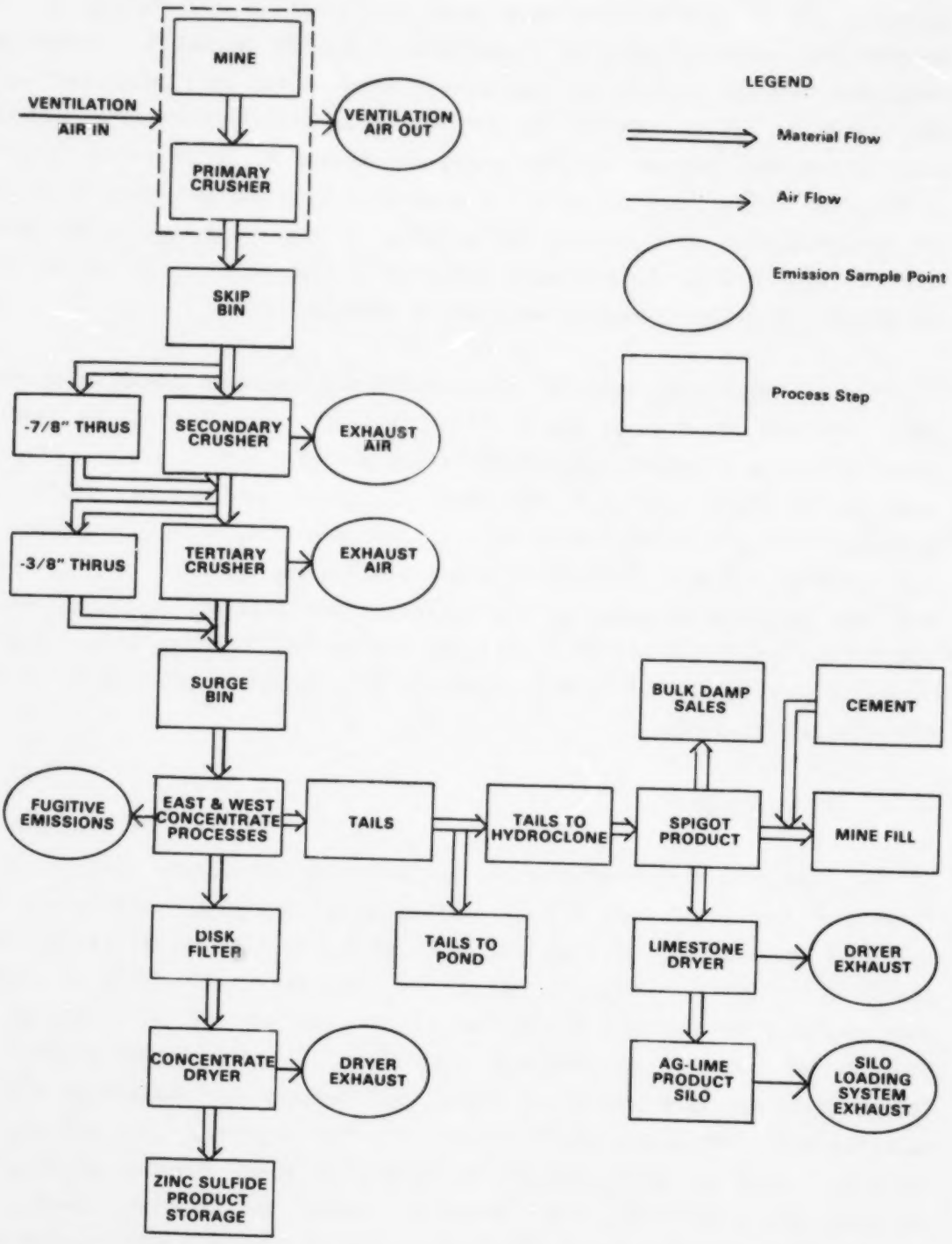

Figure 1. Schematic of Friedensville Mine and Mill Operation.

velocity and volumetric flow rate were determined by EPA Method 2. Gas samples for radon analysis were collected using EPA Method 3. Particulate emissions from the crusher and concentrate dryer stacks were determined using EPA Method 5. Stack samples for particle size distribution were collected with an Anderson cascade impactor using EPA Method 5. High volume airborne particulate samples were collected in accordance with the Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method) (40 CFR 50). Size-fractionated high volume particulate samples were collected with a Sierra high volume cascade impactor head.

Figure 1 shows the sampling points related to process steps. Figures 2 and 3 are plot drawings of the mill and tailings areas showing the sampling point locations. Gaseous samples for radon analysis were collected from all sampling locations. Samples for total suspended particulates (TSP) were collected from all locations except the roof monitors, limestone dryer, and silo loading system. Size-fractionated particulate samples were collected from the Rotoclone exhausts on the secondary and tertiary crushers, on the concentrate dryer, at the mine exhaust, and on the tailings pile. Process materials were sampled at several points so that emissions could be related to the material involved.

C. Sample Analysis

E-S made mass determinations for TSP and size-fractionated samples before forwarding the samples to EIC for radiochemical analysis. Gas (whole air) samples to be analyzed for radon-222 were shipped to EIC for arrival within 24 hours of collection. Process samples and airborne particulates on filters were analyzed by complete dissolution of the samples and separation of the elements of interest by chemical techniques. The separated uranium and thorium elements were counted on alpha spectrometers for individual isotopic quantitation. An alpha scintillation counter measured the polonium-210 activity. Lead was separated and set aside for about 2 weeks to allow for ingrowth of bismuth-210 from lead-210. After the ingrowth period the bismuth-210 was separated from the lead and was counted on a beta counter to

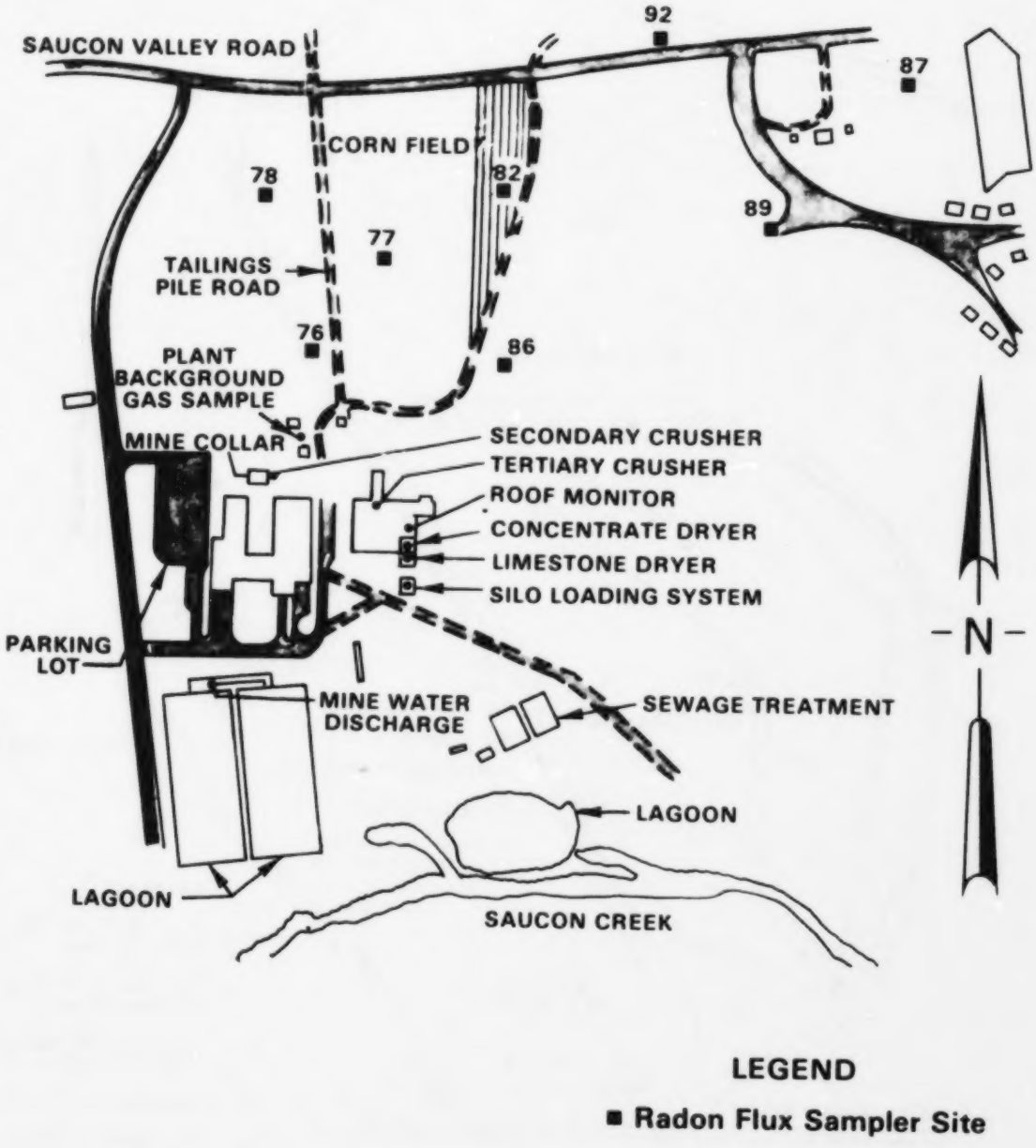

Figure 2. Friedensville Mill Plot Diagram.

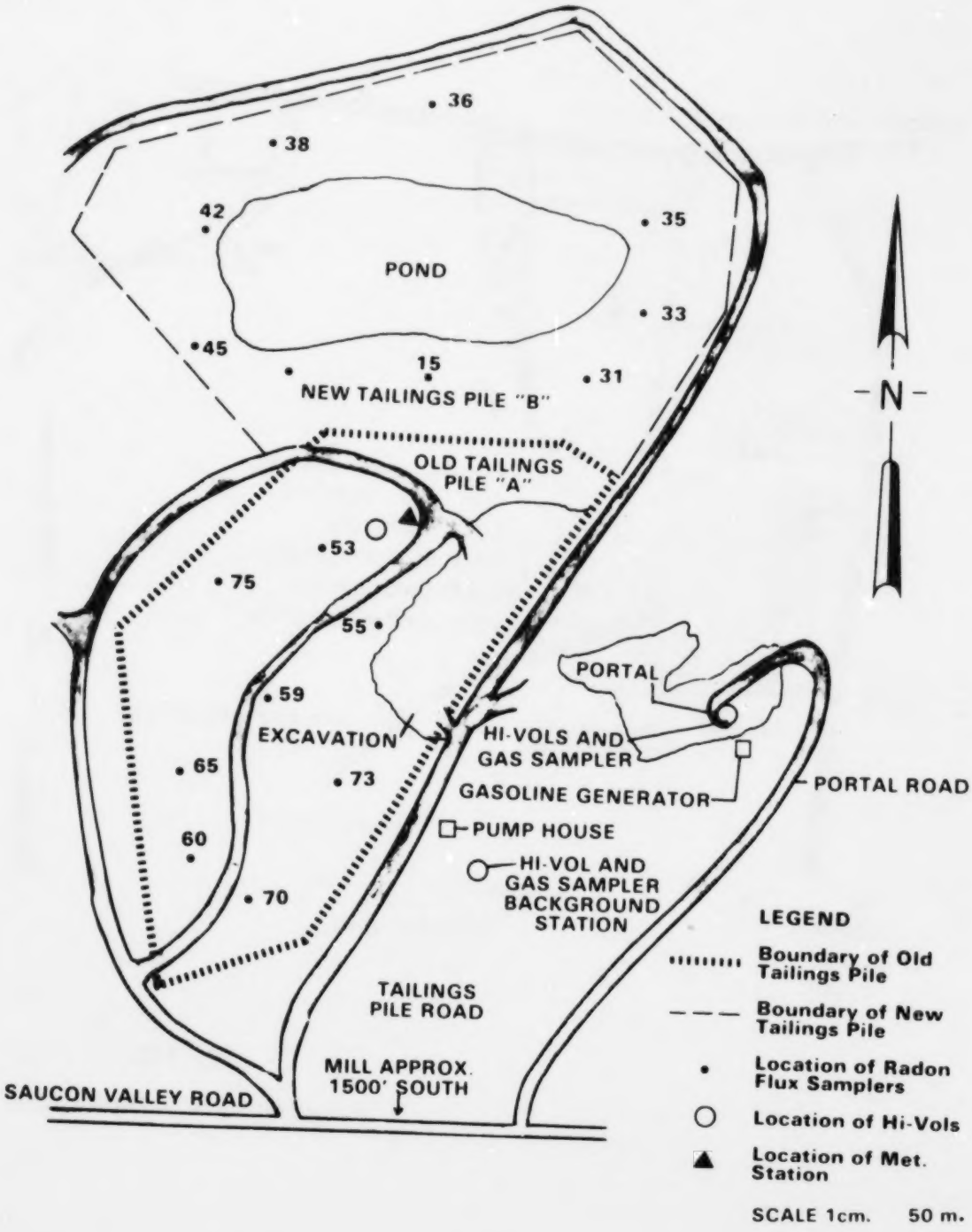

Figure 3. Friedensville Mill Tailings Plot Diagram.

quantitate lead-210. Radium was separated and enclosed as a solution in a sealed tube to allow for ingrowth of radon-222 from radium-226. After 3 weeks of ingrowth the radon gas was evolved and collected in an alpha scintillation cell. After allowing the radon daughter products to ingrow for several hours the cell was counted to quantitate radon-222. Whole air samples for radon analysis were transferred to alpha scintillation cells and counted in the same manner as radon from the radium analysis. Activated charcoal canisters placed on the surface of the tailings piles and background locations measured the radon flux. The canisters were left in place for the duration of the survey and were shipped by air express to the EPA Eastern Environmental Radiation Facility in Montgomery, Alabama for analysis of radon decay products by gamma spectrometry. This analysis permitted a calculation to be made of the radon-222 flux (emission rate per unit area) from the surface.

D. Data Reporting

The radioactivity reported for each sample, except for charcoal canisters, is the net radioactivity plus or minus twice the standard deviation (2s). The net radioactivity is the gross sample radioactivity minus counter background, and for filter samples, minus an average value for the radioactivity content of a blank filter. The standard deviation is based only on the random variations inherent in radioactivity counting and is propagated through the various steps to the final result. This random variation, plus the variable radioactivity content of individual filters, occasionally results in a net radioactivity of less than zero. Of course, there is no negative radioactivity. In these cases, as with all others, the net result must be considered along with the 2s uncertainty.

In some cases ambient radon samples are reported with negative concentrations. When those results were algebraically subtracted from effluent samples the net concentration was greater than the gross sample. Here, again, the net result must be evaluated with the resultant 2s uncertainty.

VII SAMPLE RESULTS

A. Process Samples

Ore from the secondary crusher, dried zinc sulfide concentrate, dried tailings from the dryer, and wet tailings composited from the new tailings pile were sampled. Analytical results are shown in Table 1. The radioactivity concentration of 0.18 ± 0.08 pCi/g of uranium-238 in ore, with similar results for other radionuclides in the decay chain, is equivalent to 0.6 ppm of uranium in the ore. This concentration is at the low end of the range of observed uranium concentrations in limestone.

The only consistent differences in radioactivity concentrations in process samples occur with radium-226. The results in Table 1 indicate that the concentrating process discriminates against radium, with the result that the isotope is depleted in the concentrate and enriched in the tailings. This may only be the result of analytical or sample variability. A sample of concentrate produced by the Friedensville mill was collected at the New Jersey Zinc facility at Palmerton, New Jersey as part of a group of 10 samples from mills in the United States, Canada, and Mexico. The Friedensville sample had uranium-238 and radium-226 concentrations of 0.23 ± 0.09 and 0.48 ± 34 pCi/g. Radium-226 concentrations in the other samples did not differ significantly from uranium-238 concentrations. Even at the level of 0.2 to 0.24 pCi/g found in tailings the final radium-226 concentration is on the low side of the natural range in limestone. The difference between thorium-230 concentrations in ore and the new tailings pile is considered to be only an analytical effect, as the concentration in dried tailings did not differ significantly from ore.

B. Ambient Air Samples

Ambient radon-222 concentrations at the two background stations were measured over 3-hour periods from September 25 to 28. The results are shown in Table 2. Wind measurements reported by E-S were examined to determine if emissions from the mine portal had any influence at the background stations. Only one ambient sample was collected during a period when the wind direction would indicate an effect by mine emissions. Using a Gaussian plume diffusion

TABLE 1. PROCESS SAMPLE RADIOACTIVITY CONCENTRATIONS

Sample Type	Radionuclide (pCi/g)[a]							
	U-234	U-238	Th-228	Th-230	Th-232	Ra-226	Pb-210	Po-210
Ore from Secondary Crusher	0.18 ± 0.09	0.18 ± 0.08	0.05 ± 0.02	0.15 ± 0.04	0.08 ± 0.03	0.11 ± 0.01	0.48 ± 0.32	0.23 ± 0.09
Zinc Sulfide Concentrate	0.16 ± 0.03	0.16 ± 0.03	0.04 ± 0.02	0.13 ± 0.04	0.04 ± 0.02	0.06 ± 0.01	-0.13 ± 0.96	0.19 ± 0.09
Dried Tailings	0.16 ± 0.08	0.13 ± 0.06	0.02 ± 0.01	0.13 ± 0.03	0.03 ± 0.01	0.20 ± 0.01	0.23 ± 0.33	0.17 ± 0.08
New Tailings Pile	0.18 ± 0.05	0.16 ± 0.04	0.06 ± 0.01	0.30 ± 0.07	0.07 ± 0.02	0.24 ± 0.02	0.32 ± 0.29	0.15 ± 0.08

a) Picocuries (10^{-12} curies) per gram of material, plus or minus twice the standard deviation based on counting results only.

TABLE 2. AMBIENT RADON-222 CONCENTRATIONS

Location	Date	Time On - Off	Radon Concentration (nc/m^3)[b]
Pump House	9/25	0800 - 1100	0.42 ± 0.14
Pump House	9/25	1100 - 1400[a]	0.04 ± 0.07
Pump House	9/25	1600 - 1900	-0.02 ± 0.22
Pump House	9/26	0100 - 0400	-0.02 ± 0.34
Pump House	9/26	0800 - 1100	-0.01 ± 0.10
Pump House	9/26	1600 - 1900	0.18 ± 0.26
Pump House	9/27	0100 - 0400	0.84 ± 0.44
Plant	9/28	0830 - 1130	0.68 ± 0.30
Plant	9/28	1131 - 1431[a]	0.07 ± 0.14

a) Calculated from duplicate samples

b) Nanocuries (10^{-9} curies) per cubic meter plus or minus twice the standard deviation based on counting results only

model with Pasquill's diffusion categories (Slade, 1968) for the period of 0800 - 1100 hours on September 26 an expected concentration of 0.06 nCi/m^3 was calculated. This was within the range of the reported concentration of -0.01 ± 0.10 nCi/m^3.

Examination of the data showed a possible correlation between radon concentrations and wind speed. Radon concentrations were compared to average wind speeds duing the sampling periods. An inverse relationship was obtained between wind speed and radon concentration, but the correlation co-efficient was not significant at the 5 percent confidence level. A correlation was also sought between radon concentrations and the average wind speeds during the 3-hour period preceding sample collection. The first sample was excluded because the meteorology station had not been put into operation that early. An inverse correlation was again obtained. The correlation coefficient was large enough to reject the hypothesis that no correlation existed at the 5 percent level of significance. The conclusion is that the varying radon concentrations were a function of the varying wind speeds, with higher concentrations during periods of lower wind speeds. This is an expected result (NCRP, 1975).

E-S used high volume air samplers to collect samples of airborne particulates at the pump house background station shown in Figure 3. High volume air sampler results are shown in Table 3.

C. Mine and Mill Air Samples

1. Mine Emission Samples

Seven gas samples for radon analysis, plus one set of duplicate samples for quality assurance, were collected at the mine portal exhaust. At least two samples were collected during each working shift in the mine. Concentrations measured over the 3-hour sampling periods ranged from 56 to 93 nanocuries per cubic meter (nCi/m^3) with an average of 71 nCi/m^3. No significant difference was observed between the average concentrations measured during the three work shifts. E-S measured the air flow rate of 6230 m^3/min. This results in an annual discharge of 230 Ci. Sampling results are summarized in Table 4.

TABLE 3. HIGH VOLUME AIR SAMPLER RESULTS

Location	Time-Date Collected	Radioactivity Concentration (fci/m^3)[a]							
		U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Pump House Station	1115 - 9/25 1115 - 9/26	0.37 ± 0.32	0.66 ± 0.42	0.06 ± 0.54	-0.33 ± 0.66	310 ± 7	260 ± 38	-0.16 ± 0.31	-0.12 ± 0.22
Pump House Station	1402 - 9/27 1400 - 9/29	0.06 ± 0.12	-0.02 ± 0.14	0.21 ± 0.33	0.09 ± 0.33	28 ± 3	19 ± 12	0.12 ± 0.22	0.36 ± 0.27
Old Tailings Pile	1402 - 9/27 1410 - 9/29	-0.003 ± 0.088	0.05 ± 0.16	-0.09 ± 0.26	-0.15 ± 0.35	4.4 ± 2.2	13 ± 5	-0.08 ± 0.16	-0.06 ± 0.11
Mine Portal	1203 - 9/26 1751 - 9/26	-0.08 ± 0.63	-0.61 ± 0.74	-0.58 ± 2.2	2.5 ± 2.8	380 ± 30	430 ± 80	-0.7 ± 1.3	-0.51 ± 0.89

a) Femtocuries (10^{-15} curies) per cubic meter, plus or minus twice the standard deviation based on counting results only.

TABLE 4. RADON-222 EMISSIONS FROM MINE AND MILL

Source	Time	Date	Concentration (nCi/m^3) Gross[a]	Net[b]	Annual Release Ci/yr
Secondary[d] Crusher	1630-1930	9/25	0.24±0.18	0.26±0.28	
	0100-0400	9/27[c]	1.18±0.24	0.34±0.50	
		Source Average		0.30±0.06	0.0064
Tertiary[e] Crusher	1215-1500	9/25	-0.02±0.10	-0.06±0.12	
	0100-0400	9/26[c]	0.27±0.13	0.29±0.18	
		Source Average		0.12±0.25	0.0095
Concentrate[e] Dryer	1215-1500	9/25	-0.03±0.10	-0.07±0.12	
	0835-1135	9/28[c]	0.86±0.23	0.18±0.37	
		Source Average		0.06±0.18	0.0069
Limestone[f] Dryer	1500-1530	9/28[c]	-0.06±0.19	-0.13±0.24	<0.001
Silo Loading System	1129-1429	9/28[c]	0.25±0.20	0.18±0.24	<0.001
Roof[g] Monitor	1230-1500	9/25[c]	0.03±0.08	-0.01±0.11	
	0100-0400	9/28	3.0 ±0.4	2.2 ±0.6	
		Source Average		1.1 ±1.6	0.91
Mine Portal	0800-1100	9/25	76 ± 4	76 ± 4	
	1100-1400	9/25[c]	93 ± 3	93 ± 3	
	1600-1900	9/25	64 ± 2	64 ± 2	
	0100-0400	9/26	56 ± 2	56 ± 2	
	0800-1100	9/26	58 ± 2	58 ± 2	
	1600-1900	9/26	70 ± 2	70 ± 2	
	0100-0400	9/27	78 ± 2	77 ± 2	
		Source Average		71 ± 13	230

a) Nanocuries (10^{-9} curies) per cubic meter, plus or minus twice the standard deviation, based on counting results only.

b) Radon-222 concentration in sample minus the concentration in ambient air during the sample collection period plus or minus the standard deviation based on counting statistics. The source average includes one standard deviaton based on sample variability.

c) Derived from duplicate samples.

TABLE 4 (continued)

d) 4992 hours per year operation.

e) 8344 hours per year operation.

f) 650 hours per year operation.

g) 1572 m^3/min exhaust rate at time of sampling (rate variable during year).

The only measurable concentrations of radioactive airborne particulates (Table 3) in the mine ventilation air were Pb-210 and Po-210. Measured concentrations were 0.38 $\pm$ 0.03 and 0.43 $\pm$ 0.08 pCi/m^3, respectively. At the observed flow rate of 6230 m^3/min these concentrations would result in annual releases of 1.2 $\pm$ 0.1 and 1.4 $\pm$ 0.3 mCi of the detected radionuclides. The Pb-210 and Po-210 concentrations would normally be considered as above the expected ambient concentrations. In this case, however, they are very similar to the ambient concentrations measured during the preceding 24 hours and are not considered to be elevated.

2. Mine Working Level Measurements

Radon daughter working levels were measured at several locations in the mine for comparison to MSHA's reported measurements and to radon concentrations. Working level measurements were made in the ventilation air flow at the 1350-foot level prior to reaching the working areas of the mine; at the 1350-foot level where air was picked up from the 1440-, 1410-, and 1380-foot levels; at the 1110-foot level after the air had passed all working areas; and at the exhaust portal. As would be expected, the radon daughter concentrations increased with distance through the mine. The results are presented in Table 5. Blasting on September 26 occurred at 0700 hours at the end of the previous shift. The 0.4 and 0.24 working level measurements at the portal were made downstream from the mine exhaust fan and may not represent the maximum radon daughter concentration, due to some loss in the fan and turbulent area near the fan. MSHA had measured 0.6 WL just upstream of the fan; their measurements otherwise were similar to those reported here.

3. Mill Emission Samples

Only one radon sample collected from the various emission points in the mill was significantly above background (Table 4). Samples collected from the secondary crusher and concentrate dryer produced concentrations which were greater than ambient concentrations at the time of sampling, but the associated counting error terms were such that no significance can be attached to those higher values. The one sample significantly above ambient was a net concentration of 2.2 $\pm$ 0.6 nCi/m^3 from the roof monitor of the concentrator building. Rated exhaust fan capacities give a ventilation rate at that time of 1572 m^3/min. The average annual radon-222 emission rate from the concentrator building, based on the two sets of samples, was 0.91 curies. The total radon emission rate from the mill would be less than 1 Ci per year.

TABLE 5. MINE WORKING LEVEL MEASUREMENTS

Location	Date	Time	Working Level
1350-foot level fresh air inlet	9/26	1002	0.012
1350-foot level pickup from lower levels	9/26	0920	0.029
1110-foot level after all work areas	9/26	0815	0.059
Mine Portal	9/25	1445	0.4
Mine Portal	9/29	1145	0.24

The small amount of material collected on the stack and mine portal samples, the low radioactivity content of that material, and the radioactivity of blank samples combined to yield stack effluent concentrations that were not significantly different from zero. In order to derive a better estimate of the radioactivity emission rates the mass of material collected from each source and the measured radioactivity concentration in the related process sample were used. Table 6 shows the radioactivity emission rates inferred from this. The concentrate dryer releases the majority of the particulate radioactivity emitted by the mine and mill. This results from the combination of mass emission rates; radioactivity concentration in the emitted material; and annual operating time. Of the radionuclides measured, radium-226 produces the greatest radiation dose per unit of radioactivity emitted. The Friedensville mine and mill releases less then 1 μCi of radium-226 per year.

Radon flux rates measured from the tailings piles and background locations are shown in Table 7. The differences in the average radon flux rates between the new tailings pile, old tailings pile, and background, are not statistically significant. The results, however, are consistent with expectations. Radium measurements in the ore and tailings showed lower than average concentrations. Average radon flux rates over the continental United States are about 35 $pCi/m^2/min$ (Turekian, et al., 1977). The average measured background of 16 ± 8 $pCi/m^2/min$ is lower than the average, but is within the expected range. The low radium-226 content of the tailings would be expected to result in a low radon flux, as was found in the tailings piles. Also, the new tailings pile is quite wet, which would further reduce the flux below that from the old tailings pile (Rogers, et al.). The old tailings pile has been covered with a layer of local soil and revegetated. The addition of local soil and relative dryness both probably tend to increase the radon flux above that of the new tailings pile.

VIII. POPULATION DISTRIBUTION

The Friedensville mine and mill are located in a rural area of eastern Lehigh County. Within 2 kilometers of the mine portal residences are generally scattered along several main roads, with the exception of the New Jersey Zinc

TABLE 6. ESTIMATED ANNUAL RADIOACTIVITY EMISSIONS

Source	Particulate Mass Emission Rate (kg/h)	Radionuclides (μCi/y)[a]							
		U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228
Secondary Crusher	0.0733	0.066 ± 0.029	0.066 ± 0.032	0.054 ± 0.014	0.040 ± 0.004	0.18 ± 0.12	0.084 ± 0.032	0.029 ± 0.011	0.018 ± 0.007
Tertiary Crusher	0.285	0.43 ± 0.19	0.43 ± 0.21	0.36 ± 0.10	0.26 ± 0.02	1.1 ± 0.8	0.55 ± 0.21	0.19 ± 0.07	0.12 ± 0.05
Concentrate Dryer	0.908	1.2 ± 0.2	1.2 ± 0.2	0.98 ± 0.30	0.45 ± 0.08	-0.98 ± 7.3	1.4 ± 0.7	0.30 ± 0.15	0.30 ± 0.15
Mine Portal	0.075	0.12 ± 0.05	0.12 ± 0.06	0.10 ± 0.03	0.07 ± 0.01	0.32 ± 0.21	0.15 ± 0.06	0.05 ± 0.02	0.03 ± 0.01

a) Microcuries (10^{-6} curies) per year, calculated from mass emission rate and process sample radioactivity concentrations.

TABLE 7. RADON-222 FLUX FROM SOIL AND TAILINGS

Canister No.	Location	Rn-222 Emanation Rate (pCi/m^2-min)	Average/Location (pCi/m^2-min)
15	New Tailings Pile	4.4	
31	New Tailings Pile	11	
33	New Tailings Pile	9.7	
35	New Tailings Pile	6.6	
36	New Tailings Pile	1.9	
38	New Tailings Pile	4.7	
42	New Tailings Pile	2.2	
45	New Tailings Pile	5.3	
48	New Tailings Pile	6.3	5.8 ± 3.1[a]
53	Old Tailings Pile	6.0	
55	Old Tailings Pile	8.6	
59	Old Tailings Pile	6.7	
60	Old Tailings Pile	11	
65	Old Tailings Pile	6.9	
70	Old Tailings Pile	7.3	
73	Old Tailings Pile	6.3	
75	Old Tailings Pile	9.1	7.7 ± 1.7[a]
	Both Piles Average		6.7 ± 1.8[b]
76	Background	23	
77	Background	18	
78	Background	21	
82	Background	11	
86	Background	7.4	
87	Background	17	
89	Background	27	
92	Background	4.7	16 ± 7.8[a]

a) Average ± the standard deviation of the mean
b) Average ± the standard error of the mean

Company's employee housing at Friedensville. Figure 4 shows the relationship of the mine, mill, and tailings piles to the surrounding population. The nearest residence to the mine portal is about 200 meters east. Beyond that, residences are located along the Old Bethlehem Pike about 300 meters east of the portal. Several residences are located about 200 meters south of the mill and the company-owned housing area is about 500 meters east of the mill.

IX. DISCUSSION OF RESULTS

Of the radionuclides measured, radium-226 produces the greatest radiation dose per unit of radioactivity released. The Friedensville mine and mill releases less than 1 ?Ci of radium-226 per year.

The difference in radon flux for the tailings piles and background areas results in a reduction in radon emanation to the atmosphere from soil of about 1 Ci/y. This would about offset the amount emitted from the mill.

The mine releases 230 Ci/y of radon-222. The high radon concentration in the mine atmosphere, confirmed by working level measurements, is not explained by the low radioactivity of the ore itself. The low radioactivity of the ore and the relatively solid mine interior surfaces should result in a very low radon flux from the surfaces. The most likely explanation for the presence of the majority of the radon detected lies in the water influx. Water literally rains from the mine roof and pours from the walls at the rate of 110 m^3/min. It is probable that the water, under high pressure in the rock, carries considerable dissolved radon which is released into the mine atmosphere. The water is continually aerated as it enters and is pumped through the mine. A water sample collected from the mine discharge still contained 50 pCi/l, which was probably only a few percent of the concentration in water initially entering the mine (Misaqi). It is quite conceivable, therefore, that the water had had enough radon originally dissolved in it to account for most of the estimated annual release rate of 230 Ci.

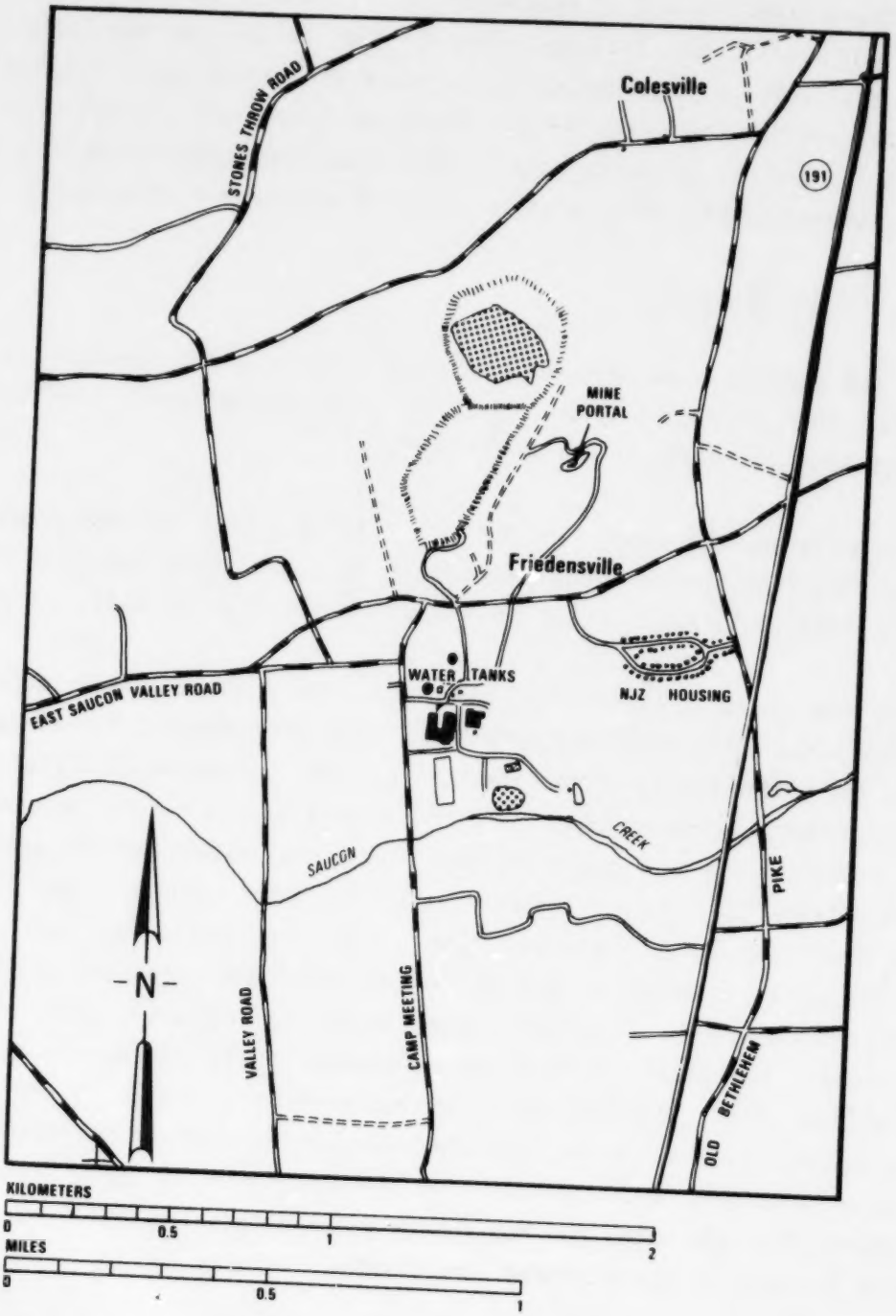

Figure 4. Map of Friedensville Mine and Mill with Surrounding Area.

REFERENCES

Code of Federal Regulations, Title 40, Chapter 1, Part 50, Appendix B

Code of Federal Regulations, Title 40, Chapter 1, Part 60, Appendix A

Engineering-Science, Emission test report. Collection of airborne radon and radioactive particulates at New Jersey Zinc Company's Friedensville Mine, Friedensville, Pennsylvania. Mc Lean, Virginia, December 1978.

Goodwin, Aurel. Mine Safety and Health Administration. Personal communication, 1978.

Misaqi, Fazlollah L. Monitoring Radon-222 Content of Mine Waters, Informational Report 1026. U.S. Department of Interior, Mining Enforcement and Safety Administration, Denver Technical Support Center, Denver, Colorado

National Council on Radiation Protection and Measurements. Natural Background Radiation in the United States, NCRP Report No. 45, 1975. Washington, D.C.

Rogers, V.C., et al. Characterization of uranium tailings cover materials for radon flux reduction. U.S. NRC Report NUREG/CR-1081, March 1980.

Slade, David H., editor. Meteorology and Atomic Energy 1968. U.S. Atomic Energy Commission, Oak Ridge, Tennessee. July 1968

Turekian, Karl K., Y. Noyaki, and Larry K. Benninger. Geochemistry of atmospheric radon and radon products. Annual Review of Earth and Planetary Sciences, 5:227-255, Palo Alto, California, 1977.